

Design a microwave transmitter using magnetron and two layers waveguides

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ABSTRACT

A magnetron is a power oscillator device used in several radar transmitters for generating the electromagnetic wave (EMW) with a constructive and fixed frequency. In this work, a radar transmitter has been carried out using magnetron operates at 2,458 MHz and two conducting layers waveguides to achieve minimum loss of the signal due to the increased temperature. The magnetron is connected with the high voltage capacitor (1.0 μ F) in order to store the alternating current (AC) signal delivered from the high voltage transformer. A waveguide parts have been used as transmission lines in view of connecting the magnetron to the antenna. These parts include two metal layers, the upper layer (outer) is advanced audio coding (AAC) 1350 aluminum conductor and the lower (inner) is copper. The waveguide dimension should be suitable to flow frequency from 2.2 GHz to 3.3 GHz. To measure the operating frequency, a waveguide adapter and a coaxial cable which combined with n-female connector have been connected to magnetron. The wave is delivering to the frequency counter by Bayonet Neill-Concelman (BNC) to n-female connectors. The promising results of the proposed work have been achieved with a maximum power, efficient return loss, acceptable voltage standing wave ratio (VSWR) and low-cost manufacturing.

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1. INTRODUCTION

Generally, radio detection and ranging (Radar) system is used to determine the range, angles, and velocity of an object (target) using an electromagnetic wave (EMW) [1]. One of the main components of the radar is the transmitter that generates the EMW and travels through the duplexer in a monostatic radar [2]. The magnetron was invented and developed since the WWII associated the microwave radar systems to detect the objects (ships and aircrafts) [3]. The radar can be classified into two types with respect to the antenna location and power transmitter. The radar systems are classified according to the antenna location to monostatic (one antenna used for transmitting and receiving through duplexer), bistatic (two antenna separated from each other one used for transmitting and the other used for receiving) and quasi monostatic (two antenna separated from each other but close together) [4].

Moreover, radar systems are classified according to transmitter power to power oscillator transmitter (POT) and power amplifier transmitter (PAT). Power oscillator is an electric device which easy to manufacture and used for small performance application due to its low cost and lightweight such as magnetron and gyrotron [5]. In this transmitter one stage or tube, usually a magnetron produces the radio

frequency (RF) pulse. Power amplifier is also an electric device which has more preference than the power oscillator due to its high performance and power in radar system such as Klystron, traveling wave tube and solid-state amplifier [6]. The magnetron is considered to be a noisy as well as experience some issues like missing pulses due to high power generation of microwave energy [7]. The application of the magnetron lies in radar (civil marine radar), medical (magnetic resonance imaging), and heating industrial (microwave oven) [8]. A microstrip patch antenna with a feed line connector operating at 2.5 GHz has been studied in [9] for the reception of signal from the unmanned vehicle and many communications application. A compact size with sharp cutoff and low insertion loss, low pass filter is presented in [10] using square and rectangular complementary split-ring resonator etched to ground layer to get a new metamaterial filter. Research by Reja *et al.* [11] a microstrip bandpass filter with regular slots is presented along with two transmission zeros and frequency response as compared with single-mode resonator. Reja *et al.* [12] designed and simulated fixed frequency microwave oscillator at 7 GHz based on metal-semiconductor field-effect transistor (MESFET) active device in order to calculate the scattering parameter in two methods (open loop gain and phase response versus frequency) and oscillator as one-port with negative resistance. The analysis and design of gyrotron oscillator with 460 GHz with both modes of TE₂₃₁ with 230 GHz and TE₀₆₁ with 460 GHz is presented in [13]. A radiation leakage of the microwave oven reducing proposed in [14] using a fractal-based open-loop resonator coupled with the open stub transmission line. Nyzam and Rahim [15] presented a heat treatment method in order to eliminate the rice weevil using microwave magnetron with approximate 900 w and 2.4 GHz. Outzguinrimit *et al.* [16] designed an optimal three phase high voltage transformer with magnetic flux leakage in order to minimize the total mass and reduce the volume of the transformer. Hussein *et al.* [17] designed two-millimeter wave microstrip antennas using substrate integrated waveguide to operate at 28 GHz for wireless communication application. The proposed strategy of this paper, the internal functional and the operating of the magnetron to produce the frequency is presented. Therefore, the two layers waveguides design (flange type), magnetron launcher and waveguide adapter are simulated and manufactured. The simulation of magnetron launcher is obtained by using microwave software such computer simulation technology (CST) studio as well as the testing of the system via using the frequency counter is carried out. The rest of the paper implicate: section 2 describes the related work of magnetron transmitter and compare the result, section 3 contains the operation of magnetron, the design and manufacture of magnetron launcher with respect to cutoff frequency, section 4 shows the combination of waveguide parts with S-parameters simulation, and the last section, section 4 includes the conclusion.

A simulated heating process based on microwave oven magnetron has been proposed in [18]. This paper presents the reflection coefficient with respect to fixed temperature (-1 °C) and different positions of the object inside the cavity as well as different temperatures and fixed final position. The thermal simulation considered to be an important key role of the proposed method in order to predict the pattern of temperature flow inside the magnetron. The drawback of this work is the increasing of the voltage standing wave ratio (VSWR) with respect to the increasing of the magnetron temperature. Moreover, the implementation by using a single layer of waveguides leads to increase the reflection coefficient (Γ).

A magnetron oven transmitter is simulated through using finite difference time domain (FDTD) has been presented in [19]. The proposed strategy measures and simulates the frequency between 2.4-2.5 GHz, FDTD simulation has been performed in order to measure the amplitude of reflection coefficient with different angular position and mesh cells of the objects inside the cavities. The work suffers from a very high reflection coefficient due to the magnetron mesh cells configuration. Meanwhile, this work has been implemented via using a single layer of the waveguides.

A 2.45 GHz electromagnetic magnetron transmitter using CST software has been presented in [20]. The proposed method compares between two cases (hot and cold) resonant cavity frequencies. This work describes the S₁₁ parameters as well as antenna height of the transmitter. The purpose of this work to achieve an acceptable return loss of the magnetron antenna transmitter in case of performed via using a single layer of the wave guides; it achieves an acceptable reflection coefficient. An industrial microwave oven magnetron has been presented in [21]. The proposed magnetron transmitter has been implemented in order to improve the output power of the injection locked magnetron. The output power of this work is rise to 20 KW which leads to convert the magnetron heat into an adjustable magnetron power. The generated frequency of the magnetron is accomplished in both experimental and simulation by using CST. This work has been performed via using a single layer of the wave guides. Moreover, the impact of the temperature on the reflection coefficient did not consider in this work.

A combination of two magnetron transmitters has been implemented in [22]. This work achieves a low-cost coherent power system with low loss waveguide based on an applicator and adjustable phase difference in two magnetrons. Practical results of return loss have been obtained via using the spectrum analyzer. A low return loss via using two magnetron transmitters and high reflection coefficient due to the implementation of the single layer waveguide has been achieved.

A wide band control feedback loop high power continuous wave (CW) magnetron transmitter with 1 KW, two cascade and 3 dB combined hybrid injection-locked by phase modulated signal and adequateness for feeding of superconducting radio frequency (SRF) cavities demonstrated by the measurement of the magnetron phase performance through transfer magnitude characteristics of the two-cascade magnetron in the modulation domain along with carrier frequency spectra measurement of magnetron is introduced by [23]. The proposed magnetron is set to exhibit superconducting radio frequency cavities to operate in intensity-frontiers GeV-scale proton/ion linacs. A concept of a highly-efficient injection-locked magnetron transmitter with high-power allowing wide-band phase and the mid-frequency power in order to control frequency of the locking signal is proposed in [24]. This paper examines powering SRF cavities of intensity frontier accelerators along with phase and amplitude control feedback loop. The injection-locked signal allows the magnetron to operate below the critical voltage. Experimental study is done with 2.45 GHz and 1 KW CW magnetron.

A low-cost highly efficient CW magnetron is proposed in [25] in order to use for jamming system instead of use high cost and low efficiency solid-state transmitter by changing the anode current of the magnetron to execute power and spectrum adjusting. Remote control communication of an unmanned air vehicle (UAV) operates at 5.8 GHz and used frequency hopping communication technique which is binary phase shift keying. The experimental design of the jamming system consists of horn antenna, double directional coupled and circulator.

A dual X-band coaxial magnetrons power combining system based on peer-to-peer locking and frequency pushing parameter effect measured by injection locking is proposed in [26]. The dual X-band is employed by single modulator in order to synchronize the pulse generation in the power combining system. When the free running frequency of one magnetron was set to 9,304 MHz, the locking phenomenon appeared with a locked frequency of 9304.41 MHz while the experiment produced a combined power of 3.09 MW for 3.5 s pulse width with a total power efficiency of 83.5%.

Injection-locking method and phase locking method for phased array system applying four power-variable phase-controlled magnetrons (PCMs) based on waveguide slot array antenna in order to achieve size reduction, low cost and durability of the system is proposed in [27]. The proposed paper demonstrated the properties of microwave beamforming and wireless power transfer based on the magnetron phased array system. The proposed slotted antenna executes angle deflection of 22.5 dB and 24.9 dB gain.

The major purpose of this paper is to design, manufacture and simulate a simple radar transmitter using two layers waveguides (the outer one is aluminum and the inner is copper) in addition to other known components such magnetron, transformer, capacitor and diode. The other purpose of this paper is to show how the EMW propagates in the magnetron waveguide launcher. The prime problems in this work are the high frequency and power of the magnetron output that effects on the human body and causes serious defect. The second problem that the devices used to measure the response such spectrum analyzer are expensive. The last problem is the difficulties in combining two layers of metals without any defect in manufacturing.

2. METHOD

The proposed magnetron transmitter is implemented in order to meet the required efficient outcomes with maximum power and low cost as well. Therefore, design and manufacture of the proposed transmitter contains several parts that can be specified as the following. The microwave magnetron, transformer, capacitor and diode which combined together in order to transmit the proposed signal. The EMW, of the combined transmitter system, travels throught the magnetron laucher and received by the waveguide adapter to coaxial cable.

2.1. Microwave magnetron

A magnetron is a high vacuum device which is used to generate the EM wave with a fixed frequency. The major assistant devices connected to the magnetron are; high voltage transformer, capacitor, and diode. The transformer is used to rise up the AC value to an acceptable tolerance level for the capacitor as well as the diode is used to allow the flow in one direction. Figure 1(a) illustrates the general structure of the magnetron and Figure 1(b) presentes physical photo of the magnetron. The basic operation of magnetron is based on the motion of electron under the combined of electric and magnetic fields. The cathode is a solid metal rob in the center of the magnetron, the electron boils from the cathode which causes the motion across the anode with a straight line [28]. The anode included slot cut called resonant cavity. Power magnets placed above and below the anode have been used to generate the magnetic field which is parallel to the cathode. On the other hand, when the electrons move from the cathode to the anode will passing though the electric field (between the cathode and anode) and the magnetic field (causes due to magnet) [6]. The microwave magnetron power is 1 KW, so there must be an overheating during generation of signal, this behavior effects on the performance of the system and causing increasing in reflection coefficient [18]. The copper can be

used to reduce the VSWR causing by heat because copper has an instantaneous thermal absorption capability better than aluminum but it dissipates heat very much slow than aluminum due to copper high thermal conductivity [29].

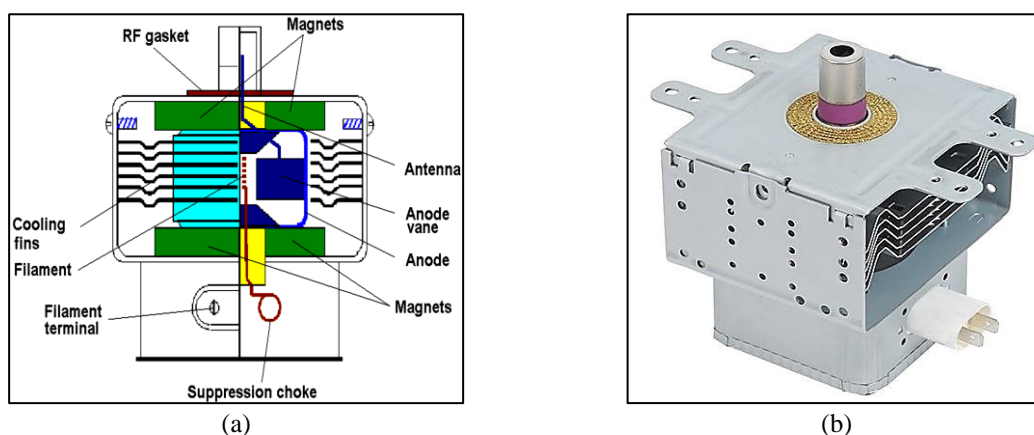


Figure 1. Microwave magnetron (a) general structure and (b) physical photo

2.2. The transformer, capacitor, and diode

Transformer, capacitor, and diode are considered to be very important parts for the operation of magnetron. The transformer is an electrical apparatus design to convert alternating value (voltage or current) from one value to another; it can be designed to level up or down the voltage and work on the magnetic induction principle [30]. The high voltage output from the high voltage transformer is 2,100~2,400 VAC. The high voltage is supplied to the components of the microwave oven such as a magnetron, a high voltage condenser, and a high voltage diode to generate a microwave of a predetermined value of frequency. Figure 2 shows a simple wiring diagram of the all-combined components together (high voltage transformer, high voltage capacitor, magnetron, and diode).

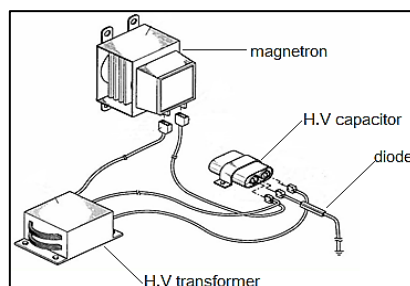


Figure 2. Wiring diagram of the transmitter

The high voltage capacitor is a passive electronic component that storage the charges and energy in high voltage application. The diode is a two terminal device which allows the flow of current in only one direction [30]. The microwave diode converts the alternating current (AC) power output of the transformer to direct current (DC), doubling the voltage to nearly 5,000 volts. This high voltage powers the magnetron to heat the food or beverage placed in the oven cavity. If the diode is burned out, the magnetron will not receive enough voltage to operate and the microwave oven will fail to heat.

For a microwave oven to operate, approximately 4 kV should be applied to the magnetron cathode. The voltage is conventionally obtained by a high-voltage transformer and it is rectified by a half-wave rectification circuit. Due to this operation scheme, the microwave power is generated in an ac mode at 60 Hz. The magnetron used in the study is capable of providing 500 W of microwave power at 2.45 GHz. The key component of the circuit is a transformer consisting of low voltage and high voltage parts in which the low-voltage part provides 3.5 V, 11 A for filament heating and the high-voltage part is for cathode biasing.

2.3. Waveguide adapter and launcher

The cutoff frequency (f_c) is the minimum frequency that should be generated in order to propagate the signal through the waveguide. It depends on the dimensions of the waveguide aperture. Furthermore, the electrical and transmission lines are both have a crucial impact on the frequency which has been propagated in the waveguide [31]. In (1) represents the cutoff frequency in TE mode (TE_{10} mode has the dominant mode of rectangular, since it has less attenuation of all modes) with respect to broad wall width (W_n) and waveguide height (H) [32].

$$f_{c_{TE10}} = \frac{c}{2} \sqrt{\left(\frac{a}{W_n}\right)^2 + \left(\frac{b}{H}\right)^2} = \frac{c}{2W_n} \quad (1)$$

$$f(h) = 1.89 f_c, f(l) = 1.25 f_c \quad (2)$$

Where C is the light speed in space $= 3 \times 10^8$ m/s, W_n is broad wall width, H is the height, $f(h)$ is the upper cutoff frequency, $f(l)$ is the lower cutoff frequency.

By calculating the broad wall width of the waveguide adapter and the magnetron launcher which is 86.36 mm, the cutoff frequency should be 1.7 GHz and the upper and lower cutoff frequencies are 3.3 GHz and 2.2 GHz, respectively. Be noted that if the generated frequency is less than the cutoff frequency, the wave will not propagate through the waveguide [31]. Table 1 shows the type of flange and the cutoff frequency. In this work the flange that used is (WR340).

Table 1. Waveguide designation and cutoff frequency

Flange type	W_n (mm)	H (mm)	f_c (GHz)	Frequency range (GHz)
WR340	86.36	43.18	1.7	2.2-3.3

The hole of the magnetron launcher which feed the antenna should be (1/4) of the wavelength to the desired represented frequency.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.458 \times 10^9} = 122 \text{ mm} \quad (3)$$

The combination of the magnetron, transformer and capacitor with the construction of magnetron launcher and waveguide adapter to coaxial cable then to frequency counter through transmission line is illustrated in Figure 3(a). The experimental work of the waveguide adapter to coaxial cable with dimension is illustrated in Figure 3(b). The N-type female adapter is used to feed the signal through coaxial cable to the n- male of SF 401 plus frequency counter (operates up to 3 GHz) by Bayonet Neill–Concelman (BNC) cable and also feed the signal to spectrum analyzer. At the desired frequency the hole should at 30.5 ± 3 mm from the waveguide wall because the radiation from the back will reflected from the wall and add to the forward radiation follow to waveguide adapter. If the distance is not correct then the radiation will scatter and reflected back to the magnetron and cause many problems such as damage of transmitter and increase the reflection coefficient.

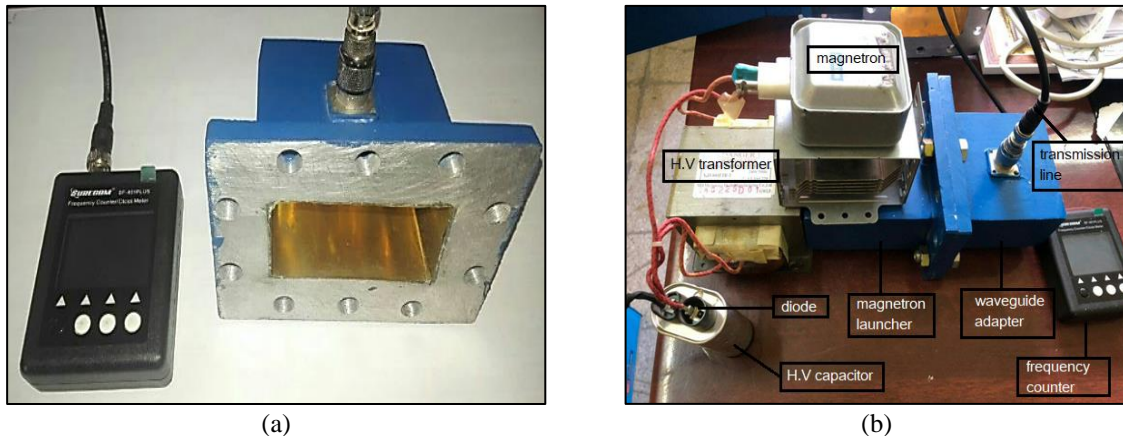


Figure 3. Transmitter manufacture (a) waveguide adapter and (b) total manufacture system

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3. RESULTS AND DISCUSSION

In this section a simulation of the magnetron launcher using CST microwave studio with the standard of WR340 and the propagation of wave through the waveguide is also presented. The magnetron launcher and waveguide adapter connection are injected in wave guide through using CST software to simulate this structure as shown in Figure 4. This structure contains two ports, the left one is for the transmitter (magnetron) and the right one is for the receiver (waveguide adapter). The wave is propagated inside wave guide from port 1 to port 2 with less reflection coefficients to gain maximum transfer power as shown in Figure 5.

Figures 6 and 7 explain the sweep parameter process of S-parameter in CST from 20 to 30 mm distance port with frequency range from 2.2 to 3.3 GHz. Table 2 presents a comparison result between presented work and other works. S11 represents the return loss of the magnetron launcher and its approximately equal to input reflection coefficient (Γ_{in}), S21 represents the wave propagate from port 1 to port 2 and it means Gain in dB. S22 represents the output reflection coefficient (Γ_o) of the waveguide adapter, S12 represents the wave propagate from port 2 to port 1. The frequency dip presents the feeding port distance from the wall, each time the feeding port distance is increased away from the wall causes an increase in the dip frequency and less VSWR as shown in Table 2. From Figure 5 the maximum degradation in return loss, S11 (-17 dB) and best insertion loss, S21 (-0.1dB) at 2.458 GHz.

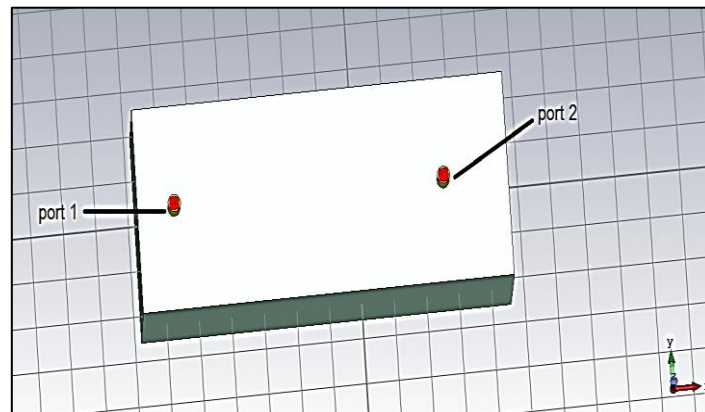


Figure 4. The combined structure of the magnetron launcher and waveguide adapter

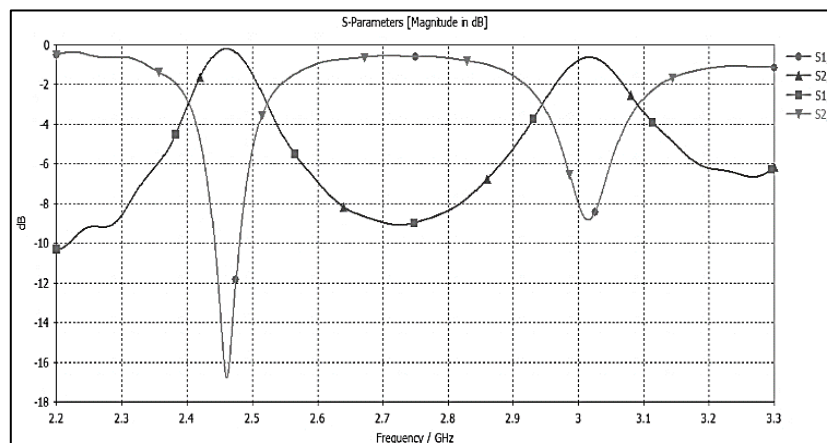


Figure 5. S-parameters results

Figure 6 clarifies the sweep parameter of the magnetron launcher's reflection coefficient with feeding port from 20 to 30 mm. Each time the feeding port distance increase causes right shifting in frequency dip and also increasing the degradation in return loss (S11) arrive to -21.8 dB, therefore reduces the VSWRs. Figure 7 clarifies the sweep parameter of wave propagation from port 1 to port 2 (gain-dB), the

variation in distance between the first feeding port and last feeding port is small but it gives enhanced in S21 with shifting in resonance frequency.

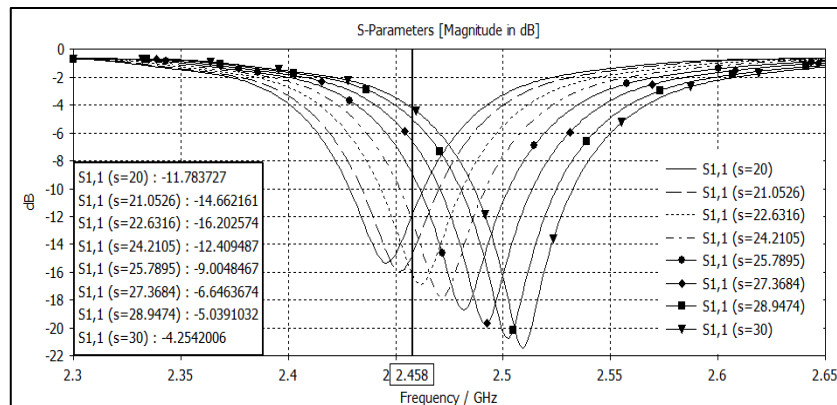


Figure 6. Sweep parameter of S11

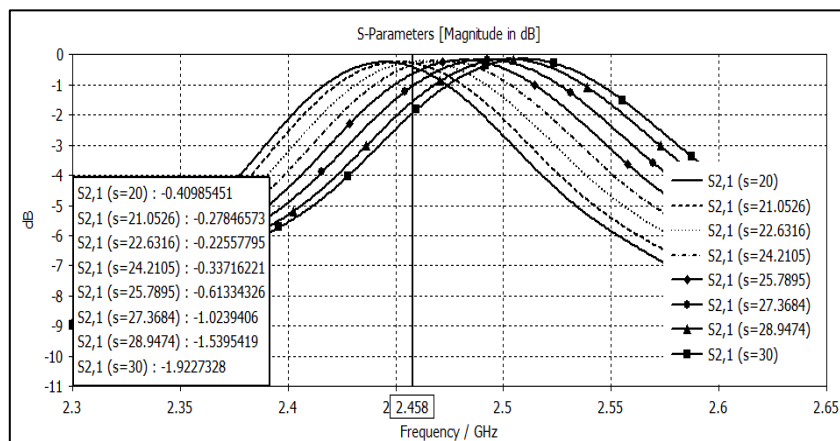


Figure 7. S21 sweep parameter

Table 2. Comparison results between presented work and others

References	Compare the results at 2.45 GHz at S=21.0526 mm			
	Presented work	[18]	[19]	[22]
S11 (dB)	-15.93068	-9.89700043	-1.83029962	-6.15
Reflection coefficient	0.15975925	0.32	0.81	0.49260634
VSWR	1.3804842	1.94117647	9.52631579	2.94171266
S21 (dB)	-0.23853774	not available	not available	not available
	Compare the results at 2.475 GHz at S = 24.7368 mm			
	S11 (dB)	-18.104695	-10.17276612	-1.72372295
	Reflection coefficient	0.12438421	0.31	0.82
	VSWR	1.284108	1.89855072	10.11111111
	S21 (dB)	-0.18459022	not available	not available
	Compare the results of 2.5 GHz at S = 28.4211 mm			
	S11 (dB)	-20.195809	-15.91760035	-3.09803918
	Reflection coefficient	0.09777089	0.16	0.7
	VSWR	1.2167483	1.38095238	5.66666667
	S21 (dB)	-0.1556992	not available	not available

The variations in results with respect to feed port distance are listed in Table 3. S-parameters, frequency dips, and VSWRs are summarized with the first feeding port, last feeding port, and five best feeding port distances that work with the magnetron frequency. From these results, the best case occurs when the feeding distance equal to 30 mm where the VSWRs equal 1.185. On the other side, the results at operating frequency (2.458 GHz) when the distance equals 22.105 mm are acceptable.

Table 3. S-parameters with respect to feeding distances

Feeding distance (s) (mm)	Frequency dip (GHz)	S11 (dB)	S21 (dB)	S12 (dB)	S22 (dB)	VSWR (1,2)
20	2.4453	-15.321	-0.249	-0.249	-15.32	1.41
21.0526	2.452	-15.931	-0.239	-0.239	-15.93	1.38
21.5789	2.4553	-16.247	-0.228	-0.228	-16.25	1.36
22.1053	2.4585	-16.557	-0.217	-0.217	-16.56	1.35
22.6316	2.4619	-16.849	-0.217	-0.217	-16.85	1.34
23.1579	2.4651	-17.153	-0.21	-0.21	-17.15	1.32
30	2.5091	-21.443	-0.143	-0.143	-21.44	1.19

4. CONCLUSION

The main idea of this paper is to design and manufacture a simple radar transmitter through using magnetron, high voltage transformer, two layers waveguides, high voltage capacitor, and diode. The process of combining all components together helps in generating and transmitting the EMW that propagates through the magnetron launcher to the waveguide adapter. The SF401 frequency counter is connected to the output of the system to check the incoming signal by n-female that works as a receiver. The metals that are used in the manufacturing of all waveguides are smelting aluminum AAC1350 (3 mm thickness) which is the external layer, and the internal layer is copper (0.5 mm thickness). The advantages of using two layers of waveguides are to transfer maximum power and much less cost. Furthermore, reducing temperature effects caused reducing the reflection coefficient.

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